POWER FACTOR IN PRACTICE

METERING THE REACTIVE K. V. A. HOUR

By RALPH MAC LAUGHLIN, '28.

ONE of the most persistent problems with which the modern power company has to contend is that of low power factor. The troubles and losses encountered in generation, transmission, and transformation, when a system is operating at a low power factor, are usually quite well appreciated by the student of electrical engineering. It follows very obviously that the power interests will endeavor, in self-defense, to investigate this item with respect to each consumer and make it, along with load factor and demand, a basis for their superstructure of rates. It is the purpose of this article to treat with one of the methods commonly employed for determining the power factor at which a customer is operating — the Reactive Kilovolt-Ampere Hour method, using the reactive component compensator.

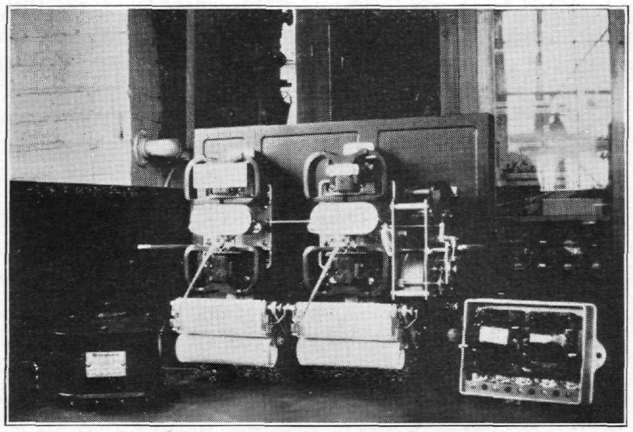

FIG. 2—TYPE RA DUPLEX RECORDING DEMAND WATTHOUR METER

REQUIREMENTS

For the smooth functioning of any system of commercial metering, in addition to employing a method which has the desired accuracy, one must be employed which readily permits of routine testing, and which does not call for apparatus too radical a departure from existing equipment. Metering devices difficult for the routine testers to become familiar with, or to test with their usual standardizing equipment, as well as those which are extremely complicated or fragile, are of doubtful working accuracy. Devices which in their adoption call for many special appliances and force good equipment into obsolescence, or which cannot readily be used in conjunction with existing apparatus, are likewise of very questionable benefit to a company. On the other hand, substantial metering devices which are adaptable to good current equipment, and which do not conflict with standardized testing practice, are bound to gain favor, both with the financial and technical branches of the organization. It is to this latter class that the reactive component compensator belongs in its own right.

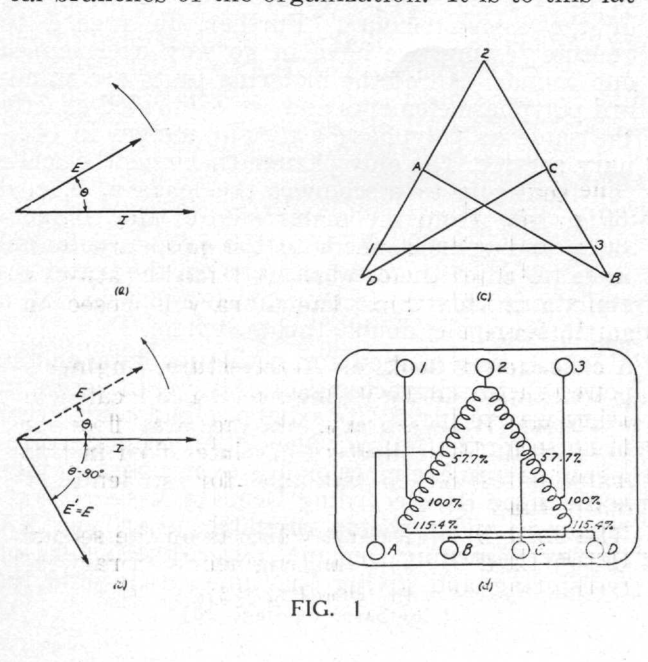

FIG. 1

THEORY

Before going into the electrical and mechanical aspects of this device and its use, it would be well, perhaps, to correlate kilowatt-hours, reactive-kilovolt-ampere-hours, and power factor, as they are the essence of the whole story. With this in view, let us consider Fig. 1-a. This represents a general circuit, in which we have the current vector I and the voltage vector E, with I lagging E by the angle Θ. The object of our study, as already stated, being power factor, we are concerned with finding the angle Θ. The power represented will be $E \cdot I \cos \Theta$. Commercially this is expressed in kilowatts, and when integrated with respect to time becomes kilowatt-hours. In Fig. 1-b we have the same current in magnitude and direction, but the voltage E′ while equal to E in magnitude, lags E by 90°. The power represented here will be $E' \cdot I \cos(\Theta - 90°)$, or $E \cdot I \sin \Theta$. Now if the vectors of 1-a be considered as representing some general circuit in question, $E \cdot I \cos \Theta$ will be the true power, and $E \cdot I \sin \Theta$ in 1-b, while representing true power for the 1-b circuit, will, in addition, represent the wattless power of circuit 1-a. This wattless power, or $E \cdot I \sin \Theta$, is commercially expressed in reactive-kilovolt-amperes, and when integrated, becomes reactive - kilovolt - ampere-hours. Calling W the true power in 1-a, and W′ the wattless power in 1-a, we may find the phase angle Θ by the following relations:

$$\tan \Theta = E \cdot I \sin \Theta / E \cdot I \cos \Theta = W'/W.$$

Having found Θ, $\cos \Theta$ will be the circuit power factor.

We have so far considered only the case of indicated power, but it is obvious that if the same interval of time be taken for the period of integration of the two power components, integrated power, as given by a standard watt-hour meter, may be used equally well, and the resulting power factor, instead of being the instantaneous as in the former case, will now be the effective for the interval in question. This justifies the use of standard watthour meters and interval demand meters which are employed in the commercial application of this principle. Our equation now becomes:

$\tan \Theta =$ Reactive K V A Hours/Kilowatt Hours

And $\cos \Theta$ is found as before. It is again to be emphasized that while the wattless power is actually measured as kilowatt-hours in the special circuit, it is termed reactive k v a hours, because this is what it represents in the main circuit.

In order to save the trouble of having to first find Θ from the tan and then look up the cos, tables have been prepared (Pamphlet GEH-613 G-E Company) giving cos arc tan x, directly.

APPLICATION

In the above treatment of the "a" and "b" circuits we have considered the general case without reference to any actual single—or polyphase system. While this theory is fundamental, yet in order to be more specific and show practical application of it, we shall discuss in particular the metering of the true and reactive power in the three-wire, three-phase circuit. This one has been selected because it is in wide use in this section of the country, is very representative in principle, and is the polyphase system in which the compensator probably finds widest application.

In practice, two polyphase metering units are used. One meters the true power in the consumer's system in the usual way. The other one meters the true power in a special system which bears the same relation to that of the consumer that 1-b does to 1-a. This latter meter consequently measures the reactive component or wattless power in the main circuit. This special system by means of which the second meter functions, is created through the use of the reactive component compensator, which will presently be described.

The compensator consists of two small auto-transformers mounted in the same case, the overall dimensions of which are about 5″ each way. The small object to the left in Fig. 2 is a Westinghouse compensator. The auto-transformers themselves are simple, each one being merely a coil of wire, with suitable taps taken off, wound upon an iron core with a closed magnetic path. They resemble in appearance the common type of audio frequency transformer used in radio work. Figs. 1-c and 1-d, taken from a Westinghouse booklet, show the phase relations of primary and secondary voltages, and the internal connections (conventionally). The phase sequence is 1-2, 2-3, 3-1. It is readily seen that E_{ab} lags $E_{1\text{-}2}$ by 90°, and that E_{cd} lags $E_{2\text{-}3}$ by 90°, also. If $E_{1\text{-}2}$ be considered the E of Fig. 1, then E_{ab} will correspond to E′, and the same with $E_{2\text{-}3}$ and E_{cd} for the other phase. We have now created the auxiliary circuit, and it is only necessary to measure the true power in it, and we shall have a measure of the reactive power in the main circuit as explained previously.

Fig. 2 shows a convenient method advanced by Westinghouse for metering both components. The meter employed is a Type RA Duplex Recording Demand Watthour Meter. This consists of two standard polyphase meter units, with the one on the left measuring the kwh and the one on the right measuring the rkvah; the demand mechanism on both units is driven by the same timing element. This, however, is merely a convenient form of meter especially adapted to this purpose. With this system of metering the reactive component, two polyphase metering units of any convenient type may be used. It is to be observed that the forming of the so-called 1-b circuit was the important part, and this once being available, the measurement of its true power was the only requirement for determining the wattless power in the main circuit. We have here described Westinghouse equipment. General Electric makes a similar compensator (Type MC Auto-transformer) for producing the 1-b circuit, and by means of standard watthour meters the same results can be accomplished as above. As evidence of the similarity of the two units, it is not unusual to find G-E auto-transformers used with Westinghouse meters. The small object on the right in Fig. 2 is a G-E double auto-transformer, with cover removed.

MEETING THE REQUIREMENTS

It will be remembered that at the start of this article the statement was made that the methods employed for the measurement of reactive k v a hours should not make routine testing difficult nor require other than the customary standardizing apparatus. In addition, we were not to require considerable special equipment nor make much of the present obsolete, and the added apparatus was not to be too complicated nor delicate. Let us briefly check up on the extent to which these requirements, or rather limitations, have been met. In the first place, the only extra device required is the compensator, which is simple, contains no moving parts to wear out, and which requires no attention on the part of the tester. Next, standard watthour metering units are used for recording the power in all cases. We have not required special equipment on this point, nor have we made obsolete any of the existing. As a corollary to this, it is obvious that the compensator and its accompanying meter may be conveniently added to a consumer's metering circuit at any time, for either temporary or permanent use, without disturbing or requiring any change in the regular equipment used for the metering of the kilowatt-hours. Further, in regard to routine testing, we have in no way overstepped our bounds. All of the metering units are standard polyphase elements and are calibrated exactly the same as polyphase watthour meters in ordinary service. The only change that must be made for testing is to disconnect the leads a, b, c, d (Fig. 1-d) from the meter side of the compensator and connect them to the proper potential leads ahead of the compensator. In the better installations this is accomplished by means of a small, four-pole, double-throw switch.

In all, this method for obtaining data on the power factor characteristics of a circuit seems in every way to justify its existence, and holds great promise for the future. One of the recent developments now in the more or less experimental stage is the Type RI, Recording Demand Meter (Westinghouse). This meter resembles the Type RA Duplex Recording Demand Meter, but instead of registering and giving the interval demand, of

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rkvah and kwh, it registers and gives the interval demand, of *kvah* and kwh, and has a device which indicates, but does not record, the instantaneous power factor. One of the features of this meter, in addition to indicating the instantaneous power factor, is that the effective power factor over a given interval may be found directly, by dividing the kwh by the kvah, without using tables as is necessary when rkvah are used. This meter, however, is considerably more complicated than the RA Duplex, and whether these added advantages will justify it, time alone will tell.

As mentioned above, we have treated only with the three-wire, three-phase system, selecting it due to its wide application and representative properties; for other polyphase systems and for certain frequencies there are various modifications, even to the extent in some cases of eliminating the compensator, but the underlying principles and theory embodied in the 1-b auxiliary circuit remain the same.

I wish to acknowledge the assistance in the preparation of this article of members of the Meter Department of the Toledo Edison Company; and the General Electric Company, and the Westinghouse Electric and Manufacturing Company, for the use of descriptive material from their pamphlets.

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BIRTH OF A SPRINTER

"What steps would you take if you saw a dangerous lion on the campus?"

"Long ones."

VALUABLE PRECEDENT

"Listen," remarked the exasperated driver over his shoulder, "Lindbergh got to Paris without any advice from the back seat."

LIBRARY FACILITIES FOR ENGINEERS

Freshmen, by all means get acquainted with your library. You may not want to use it right away, but go to the library and present your fee card for registration. You will then have full library privileges. Ask for one of the pamphlets containing the library regulations, and take out a book just to see how it is done.

First look up the book desired in the general card catalog which is located in the bibliography room. Take one of the yellow call slips from the catalog table, and fill in the call number of the book desired and other information as given on the catalog card. Sign this call slip with your name and Columbus address, and present it at the desk. The librarian will find your book in the stacks, and you may use it in the library. If the book is wanted for home use, the yellow call slip must be exchanged for a white charging card, which is signed at the Loan Desk.—Editor.